



The Virtual and the Physical

Between the representation of space and the making of space

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Wassim Jabi

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Qualitative Representation and Spatial Reasoning in a Rule-Based Computational Design Model

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Integrating social and cultural constraints in computational models remains a challenge due to the difficulties in representing them algorithmically. This research aims to find a mechanism for combining shape grammars and space syntax methods for exploring spatial-formal features that affect the social life in residential buildings. 'Spatial reasoning' as a method for understanding the social logic of spaces and the residents' behavior, integrated with 'discursive grammar' as a method for describing formal and topological relationships, are adopted. Several computational tools are used for analysing qualitative aspects, such as privacy, social interaction, and accessibility. An automated model of spatial/syntactical analysis, embedded in Rhino/Grasshopper, offers an alternative method for extracting topological relations and syntactic calculations. Using this tool, designers can add new aspects to the justified graph of Hiller and Hanson, as a representation to formal and social realities, such as orientation and geometric configuration. Results of analysis are transformed into codes, parameters, and descriptions, to be used for designing future developments, inspiring from local traditions. The target is to generate different alternatives for socially sustainable, and 'contemporary vernacular' buildings, which respect the context, and the needs of users.

Keywords: *Spatial Reasoning, Syntactic Analysis, Discursive Grammars, Computational Models, Social Sustainability, Visibility Graph Analysis*

INTRODUCTION

Computation is about manipulating ideas and solving problems in a clearly defined steps that are routinely made by computer (Terzidis 2006). This approach involves in the thinking process of the architectural design and could be used in different phases: analysis, animation, simulation, and form generation. Currently, the main focus of computational models

is primarily limited to formal and environmental requirements. Yet, qualitative factors, such as social and cultural constraints, are also important as they lead the building to be in harmony with its context and the needs of its users. Integrating these criteria in the computational process remains a challenge due to the difficulty of algorithmic representation (Yüksel 2014).

This research aims to address such social and spatial issues in the design of vertical residential developments. One approach is to draw inspiration from local traditions for generating a ‘contemporary vernacular’ building. The Middle East and North Africa (MENA) region is selected for the implementation of the model, as most of the current projects ignore the specifics of the place and the society (Wood 2013). In contrast, the vernacular model of houses shows that these precedents are good examples of socially cohesive and healthy environments (Al-Masri 2010).

‘Spatial reasoning’ as a method for understanding the social logic of spaces, combined with ‘discursive grammar’ as a method for describing formal and topological relationships, are adopted. Different computational tools are used for analysing such qualities. These software include Syntax2D for specifying spatial elements that affect the visual privacy; AGraph for carrying out syntactic calculations; and DepthmapX for understanding the behaviour of people in relation to the spatial configuration of the built environment. Finally, a combined model of spatial/syntactical analysis, embedded in Rhino/-Grasshopper, is presented.

SPATIAL REASONING AND ‘DESIGN SPACE EXPLORATION’

Jerome Bruner, in his studies about the psychology of knowing, defined ‘reasoning’ as ‘going beyond the information given’ (Bruner 1973). In the field of architecture, spatial reasoning is a logical process of analysis that enables designers’ understanding of the layout complexity, and the exploration of features that have social or experiential significance (Abshirini and Koch 2013). For instance, tracing the visual fields from a certain location in a building allows a clear evaluation of spatial elements that affect the privacy of occupants. Different methods, such as space syntax and shape grammars, could be used for carrying out reasoning analyses to derive social and spatial parameters that affect the design of the built environment.

Space syntax: a topological analysis approach

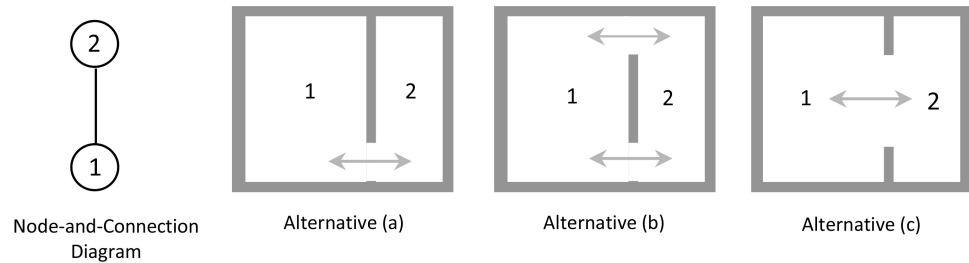
Space syntax theory, developed by Hillier and Hanson in 1984, explores social relations implicit in the architectural setting. Based on their book ‘The Social Logic of Space’, this process requires understanding physical topologies between design elements, taking into account all other spaces in the system (Hanson 1998). These relations are represented visually, through ‘justified node-and-connection’ graphs, to show the hierarchy of the overall layout. However, these diagrams do not generate descriptions for the formal reality of the design (Osman and Suliman 1994). For instance, spaces could be connected in different alternatives, and have the same justified graph (see Figure 1). Furthermore, functions located on different levels/floors need to be identified from other nodes in the system. The next section suggests how these limitations are addressed.

Hillier and Hanson (1987) also suggested that spatial relationships can be described mathematically. For example, they proposed different measurements, such as connectivity, integration, and control values, to quantify syntactical analyses. Results extracted from these tests are useful for interpreting the overall configuration and the social life in the building (e.g. high integration values indicate that spaces are busy, more accessible, and less private). In contrast, low values can mean that these functions are more segregated and more controlled in movement. However, studies focusing on how such an approach might be used for generating or inspiring new designs remain limited (Lee et al. 2013).

Shape grammars: a formal geometric analysis and generative approach

Shape grammars, developed by George Stiny and James Gips in 1970s, is a formal system that works with geometries rather than symbolic computations (Stiny and Mitchell 1978). It allows designers describing and analysing existing forms, and then generating new alternatives based on the original style. The roots of this approach builds on the work of Christo-

Figure 1
A node-and-connection diagram that is applicable for three alternatives of spatial relations (Adapted by authors, after (Osman and Suliman 1994))



pher Alexander, 'A Pattern Language', in 1977. A 'pattern', which could vary in its scale from a city to a building or a detail, addresses a problem and then recognises solutions and design practices that are balanced within the defined context, in an attempt to reconstruct the knowledge about what makes architecture beautiful (Alexander 1977).

The framework for developing a shape grammar could be outlined in four stages. (1) defining vocabularies (basic shapes); (2) determining spatial relationships; (3) formulating rules to be applied on forms; and (4) combining/articulating shapes through applying rules recursively to define a language of design or to generate new solutions (Eilouti and Al-Jokhadar 2007). After reviewing several cases that use this method for generating new spatial configurations, four types of rules could be applied: (1) additive rules, where geometries are added around the initial shape, such as the grammar of Queen Anne house (Flemming 1987); (2) subdivision rules, which divide the original shape into new zones with new proportions, such as the grammar of Malagueira house (Duarte 2005); (3) rules that are based on a grid, which start with defining dimensions and proportions for the grid, and then applying transformations, such as Palladian grammar (Stiny and Mitchell 1978); and finally (4) transformational rules, which combine additional and subdivision rules for creating openings, terraces, and roofs (Verkerk 2014).

However, shape grammars do not clarify social, cultural, and environmental dimensions of designs, as they deal only with geometric properties (Co-

lakoglu 2000). Moreover, some design possibilities have no architectural meaning or are irrelevant to the local context (Eilouti and Al-Jokhadar 2007).

Discursive grammars

To control the process of form generation and the production of unique solutions, George Stiny (1980) introduced labels, such as letters; symbols; or points, associated with shapes. Furthermore, specified equations, constraints and transformations, such as translation; rotation; reflection; or scale, could be applied to increase the number of solutions and the flexibility in design.

Another method for controlling the process is to add descriptions or textual information to the definition of rules. Rudi Stouffs (2015) defined three schemes for these descriptions. The first type is 'reflections', which reveals spatial vocabularies that form the design. The second category is 'expressions' that describe some properties of the design, such as volume, cost or manufacturing plan. The final scheme is 'design briefs', which define conditional specifications, or functional zones and their adjacency relations. The following example shows descriptions that are associated with spatial rules for generating part of a courtyard house (see Figure 2).

DEVELOPING A SYNTACTIC-DISCURSIVE MODEL FOR ENCODING SOCIAL AND SPATIAL QUALITIES OF DESIGNS

This research aims to build on the benefits of shape grammar and space syntax methods for exploring

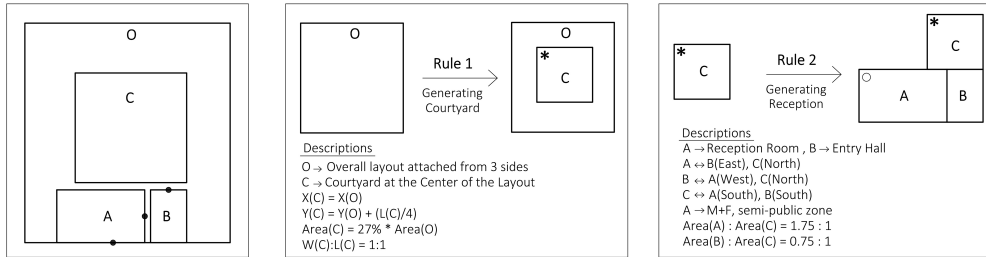


Figure 2
Part of a discursive grammar that generates the semi-public zone in a courtyard house (Authors)

spatial-formal features that affect the social life of occupants. Moreover, it tries to find solutions for the different limitations faced by these tools, through developing a syntactic-discursive model that encodes spatial constructs.

Based on a literature review of social sustainability in residential buildings (Modi 2014; Oldfield 2012), the authors identifies 13 indicators that need to be addressed in the design process. These indicators include: Population density and crowding; hierarchy of spaces; amount of living spaces that affect social interaction; human comfort; accessibility; visual privacy; acoustical privacy; olfactory privacy; spirituality; security and safety; viewing the exterior; availability of services; and hygiene.

To measure the current needs of residents and capture such qualities, we conducted a phenomenological study in the Summer of 2016, through distributing a questionnaire to 211 families from 17 countries within the study area. Furthermore, we implemented a formal-geometric study for extracting typologies of historical precedents through examining 48 traditional town houses and neighbourhoods distributed on MENA region. We then used three computational tools for carrying out these typological and syntactic analyses:

- *AGraph*: an open-access software, developed by Bendik Manum, Espen Rusten, and Paul Benze, in 2005, at the Oslo School of Architecture and Design. This 'node-and-connection model' produces syntactic calculations, and

two types of justified graphs: depth of spaces from the root space; and integration of functions (Manum et al. 2005) (see Figure 3).

- *Syntax2D*: an open-source software developed in 2007 at the University of Michigan to execute isovist analysis. It addresses the visual fields of a person at one location of the environment, and along a movement path (Wine- man et al. 2007) (see Figure 4).
- *DepthmapX*: a 'Visibility Graph Analysis (VGA)' tool developed firstly in 2000 by Alasdair Turner at the Space Syntax Laboratory, The Bartlett, University College London (UCL), and then by Tasos Varoudis (2011-2015). VGA is based on the reflection of light to understand the spatial configuration of the environment. VGA includes five types of tests: (a) connectivity analysis; which creates visibility connections between all spaces; (b) visual integration, which specifies the degree of privilege of one point over its immediate neighbours; (c) through-vision analysis, which looks at how visual fields varies within an environment; (d) depth analysis, which shows changes of direction that would take to get from the selected location to any other locations; and (e) agent analysis, which indicates patterns of movement, and the frequent use of spaces released from one point (Turner 2001) (see Figure 5).

The developed model of analysis adds new aspects to the justified graph of Hiller and Hanson, as

Figure 3
A justified graph showing the integration value for each space, produced by AGraph software (Authors)

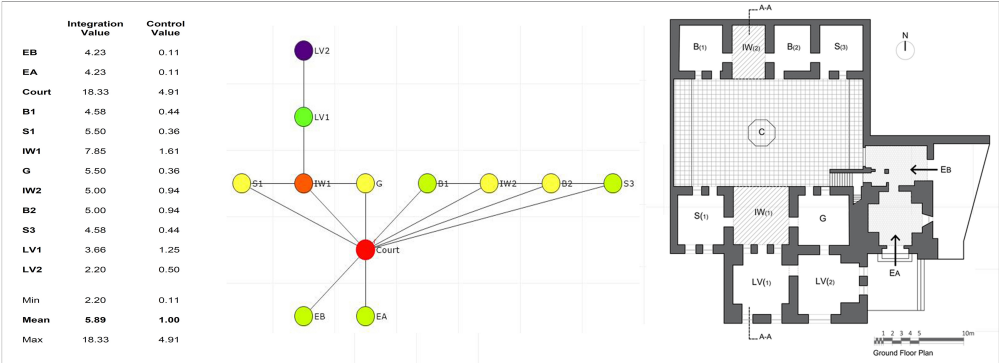
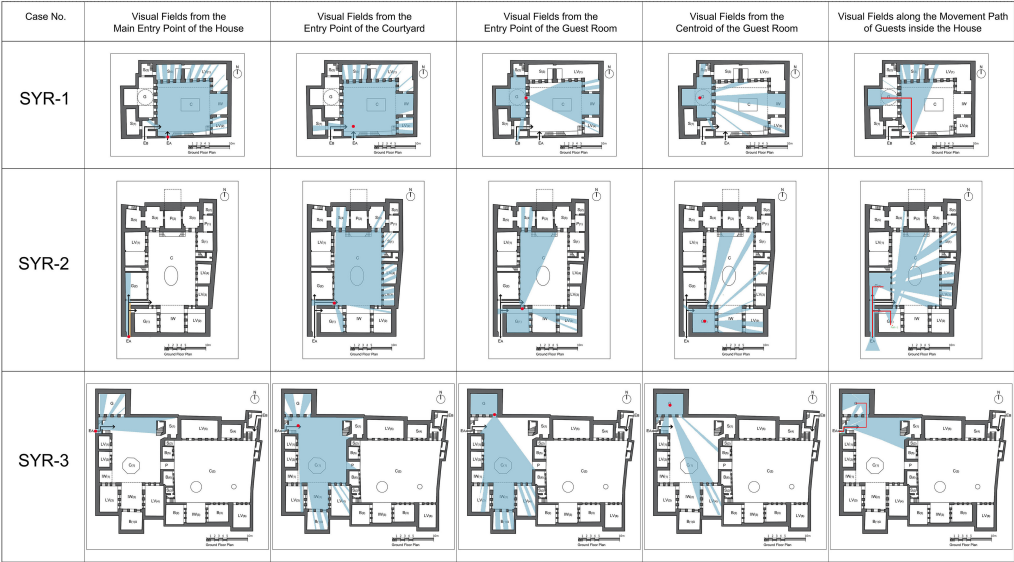


Figure 4
Samples of Isovist analysis for three traditional courtyard houses located in Syria, produced by Syntax2D software (Authors)



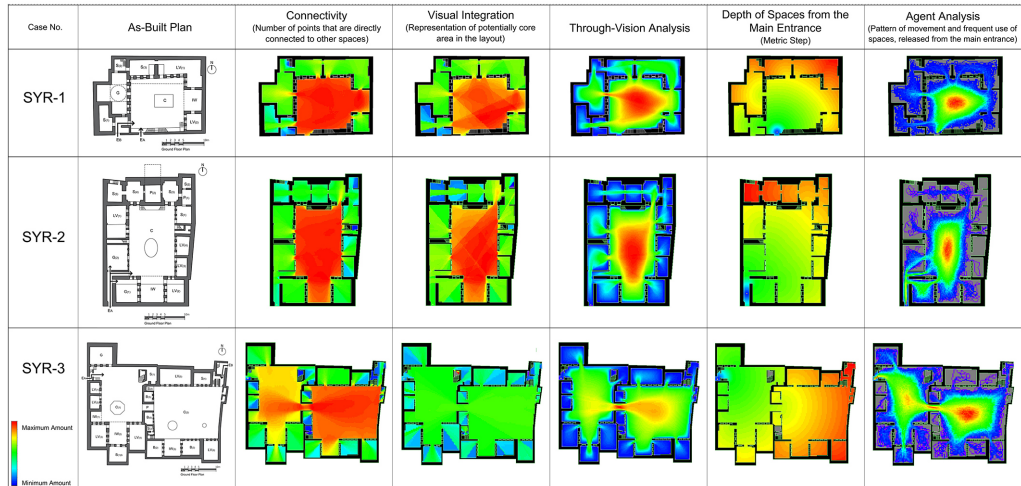


Figure 5
Samples of Visibility
Graph Analysis
(VGA) for three
traditional
courtyard houses
located in Syria,
produced by
DepthmapX
software (Authors)

a representation to formal and social realities. These issues are (see Figure 6):

1. Patterns of movement, and distances between the centre of the courtyard and the centre of each space, to analyse accessibility and security inside houses.
2. The actual geometry of each space rather than symbolic nodes. Shapes are arranged to show:
 - Hierarchy of spaces (public, semi-public, semi-private, private, and intimate);
 - Orientation (West, East, North, South, North-East, North-West, South-East, and South-West);
 - Type of enclosure (covered, open, semi-open);
 - Shared surfaces between adjacent spaces; and
 - Entry point(s) between spaces.

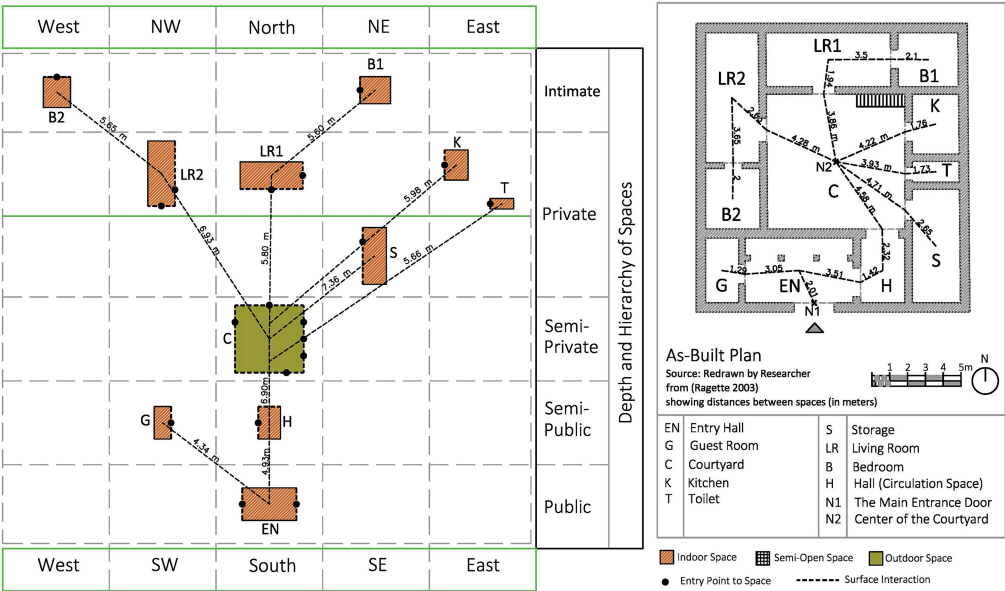
Moreover, the spatial analysis includes geometric proportions for each space; percentage of space area from the overall area of the house; area of the space in relation to the area of the courtyard; and the dominant users for each space (male, female, or both).

A COMPUTATIONAL TOOLKIT FOR PERFORMING SYNTACTIC-FORMAL ANALYSIS USING GRASSHOPPER

The above mentioned method requires from designers an extra effort to calculate spatial qualities, such as areas and proportions of spaces. Moreover, the use of *AGraph* software for extracting syntactic values requires drawing the 'node-and-connection' justified graph manually. Thus, errors could easily occur during this process. Therefore, it is useful to develop an automated computational tool for analysing floor plans in a short time of execution, and with a high degree of accuracy that does not require the user to possess an advanced level of knowledge in syntactic analysis.

For this research, Grasshopper, a plugin for Rhinoceros, is used for carrying out the needed analysis. Grasshopper is a visual scripting tool that helps the design to process (Fathi et al. 2016). It allows input data to be passed from one component to another via connecting wires. Several plugins could be downloaded for executing different utilities without leaving the tool itself. The following section illustrates a detailed workflow of the automated model.

Figure 6
Aspects added to
the justified graph
as a representation
to formal and social
realities (Authors)



Model workflow and the user interface

The model depends on generating the layout of historical cases according to a ‘space partitioning’ mechanism (Knecht and Konig 2010). It is about splitting a region into sub-spaces (cells). This geometric representational technique, using non-manifold topology (NMT), defines topological relations between adjacent spaces without any void (Jabi 2016).

The first step requires users to draw the overall layout boundary for the building (as polyline), internal partitions representing shared surfaces between spaces (as lines), and doors (as rectangles). However, thicknesses of walls are ignored. Once these features are obtained from a ‘selection’ component, the partitioning process is executed accordingly using NMT. A unique legend number is assigned automatically to each cell. This process could be applied on any layout that is composed of regular or irregular geometries.

The second step involves typing a function label for each cell, and then selecting spaces from lists ac-

ording to two criteria: hierarchy of spaces (public, semi-public, semi-private, private, or intimate zone); and type of enclosure (open or covered area). A tag component is implemented for each cell. The model, then, computes the following values, which are also delivered on the form of Excel spreadsheet (see Figure 7):

1. The area of each space, and the percentage from the total area of the house;
2. The total area for each hierarchical zone, and the percentage from the total area of the layout;
3. The distance from the centre of each cell to the centre of the main courtyard; and
4. Colour-coded syntactic values for each space, which include:
 - Integration value: describes the average depth of a space to other spaces in the system;
 - Control value: measures the degree to which an area controls access to its immediate

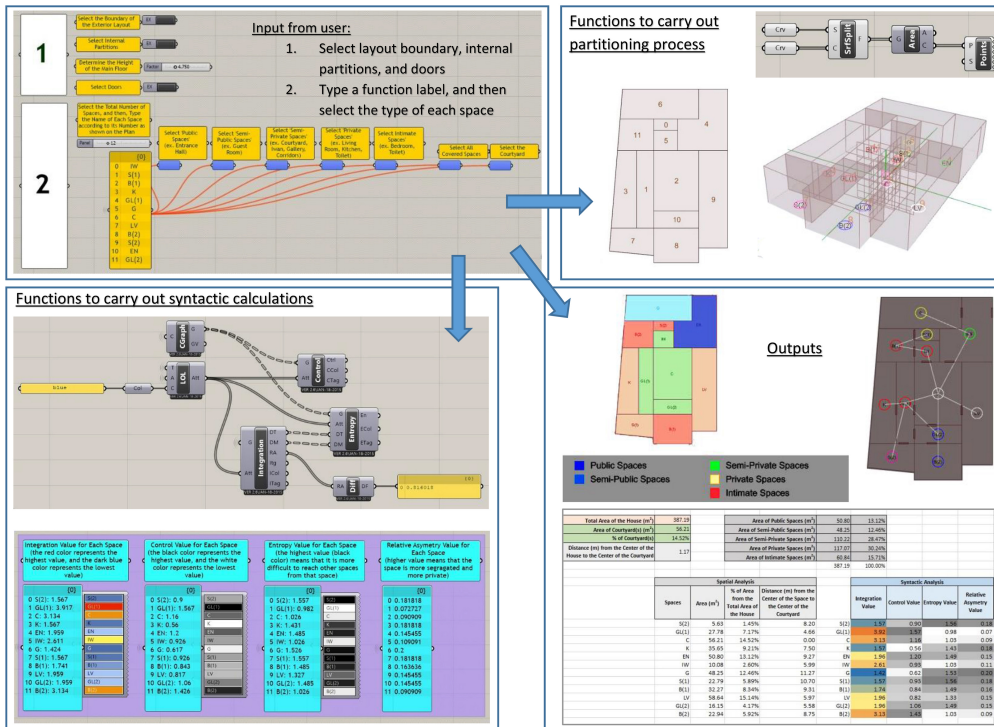


Figure 7
Model workflow and the user interface, showing input data from the user, sample of functions to carry out the partitioning process and the analysis, and the output tables and diagrams (Authors)

neighbours taking into account the number of alternative connections that each space has;

- Entropy value: the difficulty of reaching other areas from that space;
- Relative asymmetry: values that are closer to 0, means that spaces are more integrated, more accessible, and less private (minimum depth of spaces). In contrast, higher values that are closer to 1, indicate that spaces are more segregated, more controlled in movement, and more private (linear sequence of movement, and maximum depth of spaces); and
- Difference factor: values that are closer to 0

mean that spaces are more structured, while higher values, i.e. closer to 1, indicate that spaces are more integrated.

Visually, four types of diagrams are generated:

1. Orientation of spaces: based on the coordinates of the centre of each cell in relation to the centre of the layout, a unique coloured circle that indicates the location is assigned to each space;
2. Node-and-connection syntactic diagram, showing links between spaces. Each link means that there is a door/access between these two cells;
3. Hierarchy of spaces, with a colour code for

- each zone; and
4. Distances between the centre of the courtyard and the centre of other spaces.

READINGS FROM SPATIAL AND SYNTACTIC ANALYSES

When the results of syntactical-discursive analyses were examined, the following spatial features that affect the social life of occupants were observed. The traditional house consists of different hierarchical zones (public, private, and intimate spaces). The courtyard is the largest space in the house and the most accessible and connected function. Other functions are controlled and accessed through the courtyard and follow its geometric pattern with a symmetrical layout arrangement. Moreover, the depth between private areas and the courtyard provides a protected and comfortable atmosphere for family members to move inside the house easily.

The Isovist analysis and the Visual Graph Analysis (VGA) show that the privacy of the household is protected from public and semi-public spaces (the entry hall and the guest room). Different mechanisms are used for achieving this result, and to strictly limit access to the courtyard by guests. These features include the bent entrance, the use of partitions in front of the main entrance, and the size and the location of windows for guest rooms. Moreover, the spatial configuration shows that reception rooms are shallow spaces that are suited off of the courtyard next to the entry hall. In contrast, findings reveal that intimate spaces (bedrooms), which have a lower integration value, are more integrated with private spaces.

CONCLUSION

Achieving social sustainability in residential buildings requires a holistic approach for clarifying spatial qualities that affect the social life inside houses. A spatial reasoning approach is presented to understand such topologies. For instance, studying the location of each space, and measuring distances between functions, are useful for analysing accessibil-

ity and movement. Moreover, defining connections between spaces, and describing their geometry and scale, offer information about their hierarchy, the degree of social interaction that takes place within them, and their ability to provide comfort to their occupants. Analysing these factors creates a database that can be used to improve the social qualities of future developments.

The proposed automated model of analysis, offers an alternative method for extracting topological relations and syntactic calculations. This tool could be easily used to analyse floor layouts that have any size or geometry, in a short time of execution. Moreover, users do not need to know exact procedures of syntactic calculations, or draw the justified graph for the system, as the model provides them automatically. Translating such qualities into rules and parameters leads to the construction of a socio-spatial grammar that is related to the local context. This grammar will be used in the next stages of this ongoing research for the emergence of vertical residential developments that are socially sustainable, and respect the culture and the needs of its users.

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